

# Mechanical Research and Development Program for NOvA

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## Introduction

There are many outstanding mechanical issues that need to be addressed on the NOvA totally active scintillator design (TASD). The main mechanical engineering issues with TASD are how to build it and how much it will cost. The short term goal of this paper is to lay out a practical R&D plan for the rest of FY04 and all of FY05. This plan includes major milestones and estimates of effort needed.

A detailed plan has been developed in Microsoft Project for the mechanical R&D required to develop a complete design, culminating in the construction of a full scale prototype. We believe that it should be technically feasible to be ready to begin construction of this prototype by the beginning of September, 2005. The R&D plan, found in Appendix 1, is divided into several sections:

- 1.0 Design of TASD Structure
- 2.0 R&D of Assembly Process
- 3.0 R&D of Scintillator/filling process
- 4.0 Module Design
- 5.0 Full Scale Prototype Design
- 6.0 Facility Design

Each of these sections is discussed in detail below.

## 1.0. Design of TASD Structure

Under the TASD design the detector will be constructed entirely from the PVC extrusions that will make up the detector components. The modules will be alternately oriented horizontally and vertical planes. The *June 2004 Update to the NOvA (P-929) Proposal - Appendix B* can be consulted to find details of the proposed design.

In the TASD design, walls of PVC extrusions will be formed that are 17.5m x 17.5m. Other cross sections are also under considerations such as a 15m x 15m design which would require increasing the length of the detector to keep the mass constant. Decreasing the cross section of the detector can have a significant effect on the design of the extrusions because it reduces the pressure/load on the bottom extrusion which must bear the weight of extrusions/scintillator above them. Also, smaller cross sections of the detector reduce the requirements for flatness/straightness required for constructing a large plane. A smaller cross section also reduces

problems associated with handling large extrusion modules. The main issues associated with the construction of such a wall are described in detail below.

The main structural elements of the TASD design are the bottom support structure, the bookends and the PVC extrusions themselves. The first two involve relatively conventional engineering issues but the use of liquid-filled PVC extrusions on the scale of the TASD detector is quite unconventional, and will be the focus of our engineering design studies. The bottom horizontal extrusions must support the weight of all of the extrusions above without buckling. Similarly, the vertical extrusions must be able to withstand at the bottom the pressure created by 17.5m of head from the liquid scintillator. Closely associated with this is the design and strength of the manifold and the method for sealing the bottom of the extrusion. These issues though will be addressed in Section 4 below. The main questions/issues about the structure integrity of the extrusions are:

- What are the correct boundary conditions for modeling the bottom horizontal extrusions? How much support will the extrusions on either side of a given cell provide? How does the bonding method discussed above affect this? Do we epoxy bond the bottom extrusions but weld the upper ones?
- For the horizontal extrusions, how is the load from the extrusions above transferred? Is the load applied to the side wall directly or is it distributed over the side surface which will result in increasing the internal pressure?
- What are the properties of PVC and what is an acceptable stress limit?
- What is the minimum thickness that is needed to provide structural integrity? 2mm, 3mm, 4mm?? What is the thickest side wall that can be extruded?
- What is the internal geometry of the cell? Chamfers on the internal cell appear to reduce stress concentrations, how large should these chamfers be?
- What is an appropriate safety factor for failure and for buckling?
- How much area along the bottom of the extrusion needs to be supported?
- What is build up of tolerances that can be expected from the extrusions?
- What perpendicularity and flatness of each wall can be expected or is needed by the bonding method? What is the spacing between “bookends”?
- What problems associated with the thermal expansion of the PVC can be expected?
- How much bulging of the PVC extrusions cells is expected and how does this affect the bond between extrusions?
- Is it possible to epoxy extrusions together? What is the strength of the bond? What percentage of coverage would be needed to obtain an adequate bond? What ES&H issues are associated with gluing such large surfaces? How would the epoxy be applied? How much would be needed and at what cost?
- Is it possible to use PVC welding to attach the extrusions together? How reliable is this method - do we have to worry about burning through an extrusion and causing a leak?
- Is a mechanical connection between modules possible? Is it possible to have threaded rods connect and compress the stack?

The individual tasks associated with Design of TASD Structure are described in greater detail below.

### **1.1. Preliminary Analysis of Cells/Extrusions**

There are several basic questions about the strength of the extrusions and their ability to withstand the internal pressure, buckling, and other load that they will be subjected to within the structure. A simple FEA model of single cells can quickly provide some insight into the performance of cells. Much of this work has already been done. These tasks are designed to provide a basic understanding of the cells, what wall thicknesses internal chamfers may be needed to reduce stress concentrations. The tasks listed in 1.1 below, and the subsequent physical tests listed in 1.2, are needed to gain confidence in the ability of the FEA to model accurately the T ASD structure. For all of these tasks two cell geometries will be used - the commercial cells and the cell geometry in Appendix B of the NOVA proposal.

#### **1.1.1. Buckling Analysis of 1 cell with 2 & 4mm thick sidewalls.**

FEA modeling will be done on cells with various wall thicknesses in order to determine what margin of safety we can expect. One cell will be examined so that different geometries/chamfers/thicknesses can be quickly evaluated. This will provide insight into what direction the cell design should take.

#### **1.1.2. One Cell under pressure with 2 & 4 thick sidewalls**

FEA modeling will be done on cells with various wall thicknesses in order to determine what margin of safety we can expect. One cell will be examined so that different geometries/chamfers/thicknesses can be quickly evaluated. This will provide insight into what direction the cell design should take

#### **1.1.3. Tasks 1.1.1 and 1.1.2 with side constraints**

Initial analysis has shown that if the sidewalls of the extrusions are constrained, the buckling and pressure capacity increases. This will be tested by repeating tasks 1.1.1 and 1.1.2 with the sidewalls constrained.

#### **1.1.4. Repeat tasks 1.1.1 through 1.1.3 with multi-cell extrusions**

The FEA analysis will be repeated for these tasks with multi-cell extrusions. This is needed to compare to physical tests that will be performed.

#### **1.1.5. Repeat tasks 1.1.1 through 1.1.4 with various inside chamfers**

Chamfers reduce stress concentrations in the corners of the extrusions and provide additional strength. They also eliminate cell corners, where light collection from fibers is worst. FEA models of various chamfers can be used to evaluate their impact on the design and the tradeoff between cell strength and the maximum active volume of cells.

### **1.2. Basic tests on Cell Strength-Using Off-the-Shelf Commercial Extrusions**

The main purpose of this set of tasks is to compare to the FEA analysis described above in order to gain confidence in the calculations and the ability of the FEA to accurately model the T ASD structure.

#### **1.2.1. Buckling tests of single cell using 4", 8" and 16" long cells - horizontal loading**

The purpose of this test is to compare to tasks 1.1.1 described above.

#### 1.2.2. Buckling tests of multi-cell panel with 2ft and 4ft panels

The purpose of this test is to compare with the FEA models described above. This test has been started.

#### 1.2.3. Buckling test of a single cell using 4", 8" and 16" long cells - Vertical loading

The purpose of this test is to compare with the FEA models described above. This test has been started.

#### 1.2.4. Buckling tests of multi-cell panel with 2ft and 4ft panels - vertical orientation

The purpose of this test is to compare with the FEA models described above. This test has been started.

#### 1.2.5. Pressure tests on single cells

The purpose of this test is to compare with the FEA models described above and to determine the strength of cells under pressure. This test has been started.

#### 1.2.6. Pressure tests on multi-cell panels.

The purpose of this test is to compare with the FEA models described above and to determine the strength of cells under pressure. This test has been started.

### **1.3. Basic Material Property Testing**

The modulus, and strength of PVC is dependent upon many factors such as the amount of titanium dioxide. It is very important to be able to quantify the affect on the PVC mechanical properties of variations in composition. Also, it is important to perform tests so that accurate values of the mechanical properties are used in the FEA and other structural calculations.

#### 1.3.1. and 1.3.2. Tension tests on different thicknesses and types of PVC.

The purpose of the tension tests is to determine the yield and modulus of the PVC and the dependency on titanium dioxide and plasticizer. Tension tests will be conducted on samples taken from the commercial extrusion and the custom extrusions. It is planned that the custom extrusions will also be made without any titanium dioxide. Also, tests will be conducted from other purchased samples of PVC of different composition in order to determine the relationship between plasticizers, etc. on the strength of the material.

#### 1.3.3. Creep tests

Questions on the creep properties of PVC have recently arisen. Creep tests under normal conditions and accelerated creep tests will be conducted on samples of PVC cut out of the commercial and custom extrusions in order to generate the creep curves and determine these working stress below which creep is not a problem.

### **1.4. R&D on Welding Process**

Several tests have done using a thermal welding process. These tests have proven that it is possible to weld PVC sheets together, however, the quality and strength of these bonds is heavily dependent upon the skill of the operator. This process has the possibility of burning through the outer walls of the cells and producing leaks. Further R&D is needed to see if this is a viable method for bonding extrusions together and if ultrasonic welding process offers a better solution.

#### 1.4.1. Shear and Tension tests on thermally welded pieces

Using the existing thermal welding equipment several test pieces will be made according to ASTM standards and tested in tension and shear to evaluate the strength of the bond and how variations in the welding process affects this strength.

#### 1.4.2. Identify ultrasonic welders

ANL has done a preliminary study of ultra-sonic welders and found that these typically are used to bond very thin sheets of plastic/PVC together. Further investigation will be done to see if thicker sheets (1-2mm) can be bonded in this method and to identify equipment that could be used.

### **1.5. Review of Epoxies**

Epoxies will be used to assemble modules and to bond extrusions together to form the T ASD structure. Calculations have begun on the potential strength/coverage that is needed. R&D is needed to identify potential epoxies that are low cost but still meet the strength requirements.

#### 1.5.1. Identify typical Epoxies that are used on PVC

PVC is a common structural material used mainly in piping. An initial investigation will examine what epoxies are used in industry to commonly bond PVC and how appropriate these epoxies are for the T ASD application given the large quantities, ES&H issues, and strength requirements of the experiment.

#### 1.5.2. Identify Structural “tape” epoxies

Tape epoxies are commonly used in the automatic industry. They offer the potential of ease of application and the lack of noxious fumes. However, they typically need to be cured at high temperatures.

#### 1.5.3. Calculation of Required Strength/coverage

In order to select any epoxy and to determine the coverage that is needed basic calculations are needed on the forces between extrusions within the T ASD structures.

### **1.6 Design of Bookend/Bottom Support**

In the T ASD design a bookend is needed to provide an initial flat surface on which to begin construction. This bookend will also support and horizontal forces during construction. Similarly a bottom support is needed that is sufficiently flat and provides any access that is needed for leaks, servicing, etc.

#### 1.6.1. Identify Potential Loads

The first step in the design of the bookend/bottom support is to identify potential loadings on the structures. This is fairly straightforward for the bottom support which mainly has to support the weight of the detector. However, the loads on the bookend are not so clearcut and depend on the potential angle of the T ASD structure, thermal expansion, and potentially liquid pressure.

#### 1.6.2. Determine required flatness of planes

An investigation is needed to determine how flat each plane needs to be and what is achievable. Initial calculations have shown that the cumulative affect of even a small out of flatness results in increased loads on the epoxy.

#### 1.6.3. Calculation of Thermal Expansion/loads

Thermal cycling of the T ASD detector can result in increased stresses in the pvc extrusions as well as excess liquid in the modules. Basic questions that need to be addressed are:

- What is the volumetric expansion of the liquid scintillator?
- What is the heat capacity of the assembled T ASD structure? How long does it take for the entire structure to increase in temperature due to changes in the ambient conditions?
- How do restraints on the pvc extrusions affect the volumetric thermal expansion of the PVC extrusions?
- What induced thermal stresses can occur in the PVC extrusions because they are restrained within the structure?

#### 1.6.4. Investigation of Failure modes of structures

All potential failure modes of the detector structure need to be identified and analyzed. Mitigation strategies will take into account detector performance and cost issues.

### 1.7. Testing of Epoxies

From tasks 1.5 above a determination of a potential epoxy will be made. Tests need to be done for our specific application.

#### 1.7.1. and 1.7.2. Tension and Shear tests of Epoxy.

These are basic ASTM tests that will be conducted to evaluate the epoxy for our application.

### 1.8. Design of a 27ft x 15ft Mechanical Prototype using Off-the-Shelf Extrusions

A cheap and easy way to answer many of the mechanical construction issues described above is to construct a large mechanical prototype using off-the-shelf commercial extrusions. At 27ft the mechanical prototype will be almost half size of the proposed detector. The prototype will contain enough layers to verify predictions about the mechanical behavior of very long structures, and may be several meters deep. The purposes of this prototype will be the following:

- Evaluate the flatness of large extrusions and how this affects the assembly.
- Evaluate the minimum amount of epoxy needed for structural strength and to eliminate bowing of the extrusion.
- Evaluate methods for assembling individual extrusions. The initial plan calls for assembling 1 extrusion at a time. It is possible at a later date to construct a fixture to assemble an entire “plane” of several layers of extrusions at a later date.
- The extrusions will be filled with water and pressurized to evaluate deflections of an assembled structure.
- A temperature differential will be applied by placing heaters at the top or bottom of the prototype to evaluate the effect of thermal expansions.

#### 1.8.1. Design bookend support structure

The 4-layer PVC extrusion structure must be constrained to be vertical, flat and mechanically stable. This will be accomplished by attaching it to a 27ft high by 15ft wide vertical bookend

structure. A preliminary design has been developed for a concrete-block, unistrut and particleboard bookend structure in Bldg 366 at Argonne.

#### 1.8.2. Design 4-layer extrusion structure

The extrusion structure will consist of 4 layers of 27ft high by 15ft wide off-the-shelf extrusions (designed for the construction of agricultural building walls). Alternating layers with horizontal and vertical tubes will be attached to each other and to the bookend with a suitable adhesive. The planes must be flat and vertical to appropriate tolerances and the structure must be mechanically stable. Suitable facilities for filling the extrusions with water, for performing for tests with controlled overpressure and for longer term creep measurements will be provided.

#### 1.8.3. Decide upon handling/assembly method

One of the main reasons for this mechanical prototype is to gain experience about how to handle large extrusions and subsequently assemble them together while accounting for any bowing. A method for handling the extrusions and mounting them to a plane needs to be evaluated and designed.

#### 1.8.4. Strongback design

A plan and design for the strongback which will be used to assemble the prototype planes, to raise either entire planes or individual extrusions, needs to be made.

#### 1.8.5. Choose epoxy to use

Based on the evaluations made in the tasks above, a determination of which epoxy will be made in order to evaluate it during a real assembly process.

#### 1.8.6. Design method for sealing ends of extrusions

The extrusion in this prototype will be filled with water and pressurized to mimic the actual conditions seen in the full size detector. A method for sealing the extrusions is needed to accomplish this.

### **1.9. Construction/Testing of 27ft x 15ft Mechanical Prototype with Off-the-Shelf Extrusions**

#### 1.9.1. Order/Receive Extrusions

An order has already been placed and the extrusions are expected at ANL by August 9<sup>th</sup> for enough extrusions to construct four plates that are 27ft x 15ft.

#### 1.9.2. Assemble Support Structure

The bookend, bottom support, and fixturing required for assembly need to be fabricated.

#### 1.9.3. Assemble Extrusions into planes

The four planes of horizontal and vertical extrusions will be assembled.

#### 1.9.4. Fill with Water/Pressurize and measure deflections

The extrusions will be filled with water and pressurized to mimic the maximum pressure expected in the full size detector. Dial indicators will be placed at various points along the

bottom of the plane to measure bowing and sidewall deflection of the extrusions. A Bronson scope will also be set up to measure overall deflections and flatness of the plane.

### **1.10. Design and Build 8 m x 8 m Mechanical Prototype using Custom NOvA Extrusions**

The 27ft x 15ft prototype used off-the-shelf commercial extrusions to gain experience with large PVC structures and assembly techniques rapidly and inexpensively. The 8m x 8m prototype will constitute a much more realistic demonstration of mechanical properties of the final detector and may also provide the first opportunity to instrument extrusion tubes with wavelength-shifting fibers and readout systems. This half-scale detector will contain enough layers to verify predictions about the mechanical behavior of very long structures, and may be several meters deep.

#### **1.10.1. Design of Final Extrusion**

Based on the R&D in the previous tasks as well as tasks 4.0 Module Design a final design of the extrusion geometry will be determined.

#### **1.10.2. Order final Extrusion**

Extrusions of the final size will be ordered in order to construct an 8m x 8m prototype.

#### **1.10.3. Design of a 8m x 8m Mechanical Prototype**

A mechanical prototype that is 8m x 8m will be constructed using modules/extrusions that are identical to those anticipated in the full size detector. This is a proof of concept prototype and a way of testing everything that had been learned in the previous tasks. In addition, it is a way of testing out the final module components such as manifolds, end seals, etc. This prototype will be filled with liquid scintillator and fibers.

#### **1.10.4. Construction/Testing of 8m x 8m prototype**

The 8m x 8m prototype will be constructed using the methods anticipated for the full size detector. The prototype will be tested at the anticipated pressures and deflections measurements will be made. In addition, instrumented modules will be monitored for at least several months to study creep effects in PVC under conditions similar to those in the NOvA detector.

## **2.0. R&D of Assembly Process**

This set of tasks is closely coupled with section 1.0 Design of TASD Structure described above. The purpose of the tasks in this section is to evaluate how individual modules will be handled and assembled together into a final structure. The main issues that need to be addressed are:

- Will entire planes be constructed and then raised as a unit like MINOS or will individual extrusions be stacked?
- What type of fixturing is needed to insure that individual extrusions/modules are flat and compressed sufficiently against the previous plane?
- How will 17.5m long extrusions/modules be handled?

## 2.1. Evaluation of Assembly Process

We will perform engineering studies of the two detector assembly processes that have been proposed. The Preamsembled Wall method involves the construction of multilayer assemblies for full cross section walls of extrusions that are raised from horizontal to vertical after assembly and attached to the detector. The Individual Extrusion method involves the attachment of individual extrusions to the working face of the growing detector.

### 2.1.1. Preamsembled Wall assembly method

A design analysis will be done of a MINOS-type fixture for lifting an entire stack of several planes of modules at one time. The questions that need to be addressed are:

- How big is such a structure and how stiff does it need to be?
- How will it be lifted from horizontal to vertical?
- How will it press the stack of modules against previously assembled modules?

The experience gained in the construction of the 27ft x 15ft mechanical prototype will be used extensively in this evaluation.

### 2.1.2. Individual Extrusion assembly method

A step by step installation procedure for building detector walls from individual extrusions will be developed. This will include estimates of manpower and time requirements, for comparison with corresponding estimates for the preassembled wall assembly method.

## 2.2. Conceptual Design of Assembly Fixtures/Tooling

Fixtures will be designed for rigging individual, instrumented extrusions into place and for providing appropriate working platforms for installation workers.

## 2.3. Development of Module Storage Plan/Assembly concept

The T ASD structure requires a large number of modules. The movement of these modules must be coordinated between the factories, storage facility and with the rate of detector construction.

## 3.0. R&D of Scintillator/filling Process

There are many issues that must be resolved for the liquid scintillator:

- What problems can be encountered during filling? Is there a possibility of trapped air or bubble creation?
- Can extrusions be emptied of scintillator and refilled if problems develop?
- Does scintillator have to be mixed on site? Does it need filtering? How fast can we fill?
- What is the delivery rate of scintillator? How much storage is needed on-site?
- What is the method for distributing the scintillator from a storage tank to the modules?
- What spillage containment is needed? Do we have to have containment for the entire detector volume? If not, what fraction?
- What quality assurance tests and instrumentation are needed?

### 3.1. Filling techniques and bubble control

Research needs to be done on how to handle and distribute the liquid from storage areas to the modules. What is the maximum rate of fill? What fittings on the modules are needed to facilitate filling? How do we know if a module is filled? How are bubbles controlled?

### 3.2. R&D on Scintillator Delivery/storage issues

This task will address the rate at which scintillator can be delivered and at which it will be used to fill modules. From this the amount of storage will be determined. Also, issues related to the mixing and uniformity of the scintillator will be addressed.

### 3.3. Scintillator distribution to modules

This task will address the distribution/pumping system for getting scintillator to modules.

## 4.0. Module Design

In both the baseline and the TASD design modules will be constructed from the PVC extrusions. The design of these modules will be very similar and therefore will have common issues.

- What is design of the manifold? Do we need internal fiber guides like the MINOS modules? Will we be using a connector or a cookie? Does this connector/cookie have to be leak tight?
- What air vents are needed in the manifold?
- What connections on the manifold are needed for filling the module with scintillator?
- How will the manifold be bonded to the extrusion?
- What fiber size will be used? What is its maximum bend radius? Does it interact with the scintillator over the long term?
- How do we insert the fiber into the extrusion? How do we keep the fiber anchored at the bottom of the extrusion? How do we keep the fiber out of the corners of the extrusion?
- How is the bottom of the extrusion sealed? Is it necessary to have a each cell connected to each other for the scintillator flow? What is the maximum pressure that the bottom connection needs to withstand?
- What are the pros and cons of possibly having the modules at a 45 degree angle?
- Does the sequence of filling the modules matter? For example, in the TASD design adjacent modules may need to be filled together in order to provide support. What implications does this have for the assembly of the detector?
- What cleaning of the extrusions is required?
- What program/method of leak testing will be performed on completed modules and how will leaks be fixed?
- How can some of the module assembly tasks be automated? What factory machinery/fixtures/tooling is required?

### 4.1. Design of Manifolds

Manifolds are needed at the end of each module to route the fibers to a connector or cookie. These manifolds must route the fibers and attach to the extrusions in a leak tight way and be able to accommodate changes in liquid volume caused by temperature changes.

### 4.2. Design of Bottom Seal

The bottom of each module must be sealed. This seal must be able to withstand the maximum pressure.

#### 4.3. Design of Fiber insertion Method

Each cell within an extrusion will have two fibers running along its length. These fibers will then be routed through the manifold to a cookie or connector. A method of inserting the fibers along the 17.5m length of each cell and anchoring them in place is needed.

#### 4.4. Module Fabrication methods

A factory and assembly process must be designed for attaching manifolds and end seals, inserting fibers, and polishing a connector/cookie.

#### 4.5. Pressure/Leak Tests in Module Construction

A method needs to be developed to insure that each module is leak tight after fabrication

### **5.0. Full Scale Prototype Design**

During the last few months of FY 2005, work will begin on a plan to construct a full scale prototype of the NOvA detector using PVC extrusions that can be instrumented to record cosmic ray tracks. This detector will be at least several meters long.

#### 5.1. Identification of a building

There are not many facilities that can support a 17.5m high prototype. A building needs to be found at ANL or FNAL where this construction can take place.

#### 5.2. Design of Support Structure

The bookend/bottom support structure for the full scale prototype will be substantial. Design work needs to begin early on the structure and how they can be integrated into the facility that is chosen for the construction.

#### 5.3. Design of liquid handling/storage/filling

Background work is needed on calculating the amount of liquid needed, how it will be delivered, stored, and mixed.

#### 5.4. Design of Modules and Fabrication

A plan needs to be developed how the prototype module components will be constructed and assembled.

#### 5.5. Design of Structure Assembly method

Work needs to begin on how the 17.5m long modules will be handled and assembled together in the prototype. Will final assembly fixturing/tooling be constructed or will some temporary fixturing be used?

## **6.0. Facility Design**

The NOvA detector will need a building with support services.

- What size of building is needed? What crane size and travel is needed?
- What accommodations are needed to contain a spill?
- What piping/storage tanks are needed for the scintillator?
- What office space is needed?
- What are the requirements for temperature and humidity?
- What storage space is needed during assembly?

### **6.1. Preliminary Building Design with no Overburden**

The requirements for the building for the final detector need to be developed, including installation and operating support services.

### **6.2. Preliminary Building Design with an Overburden**

A conceptual design study will be conducted to determine what modification of the building design would be required to support an overburden consisting a few meters of earth.

### **6.3. Leak Containment Design**

The method for detecting and containing leaks needs to be evaluated.

## Appendix 1. Microsoft Project Schedule for NOvA Mechanical R&D Tasks

The following figures show the Project 98 printout of the R&D Plan.

ID	Task #		Task Name	Duration	Start	Finish
1						
2	1.0		Design of TASD Structure	375 days	Fri 7/9/04	Thu 12/15/05
3	1.1		Preliminary Analysis of Cells/Extrusion	60 days	Fri 8/27/04	Thu 11/18/04
4	1.1.1		Buckling Analysis of 1 cell	60 days	Fri 8/27/04	Thu 11/18/04
5	1.1.2		1 cell under pressure	60 days	Fri 8/27/04	Thu 11/18/04
6	1.2		Basic Tests on Cell Strength - Using Commercial Extrusion	60 days	Fri 7/9/04	Thu 9/30/04
7	1.2.1		Buckling test of single cell using 4", 8", and 16" long cells - Horizontal orientation	60 days	Fri 7/9/04	Thu 9/30/04
8	1.2.2		Buckling test of multi-cell panel with 2ft, 4ft panels - Horizontal orientation	60 days	Fri 7/9/04	Thu 9/30/04
9	1.2.3		Buckling test of single cell using 4", 8", and 16" long cells - Vertical Orientation	60 days	Fri 7/9/04	Thu 9/30/04
10	1.2.4		Buckling tests of multi-cell panel with 2ft, 4ft panels - Vertical Orientation	60 days	Fri 7/9/04	Thu 9/30/04
11	1.2.5		Pressure tests on single cells	60 days	Fri 7/9/04	Thu 9/30/04
12	1.2.6		Pressure tests on multi-cell panels	60 days	Fri 7/9/04	Thu 9/30/04
13	1.3		Basic Material Properties Testing	60 days	Fri 7/9/04	Thu 9/30/04
14	1.3.1		Tension tests on different thickness and types of PVC	60 days	Fri 7/9/04	Thu 9/30/04
15	1.3.2		Tension tests on Material out of commercial and special order Extrusions	60 days	Fri 7/9/04	Thu 9/30/04
16	1.3.3		Creep tests	60 days	Fri 7/9/04	Thu 9/30/04
17	1.4		Review of Epoxies	60 days	Fri 7/9/04	Thu 9/30/04
18	1.4.1		Identify typical epoxies used on PVC	60 days	Fri 7/9/04	Thu 9/30/04
19	1.4.2		Identify structural "tape" epoxies	60 days	Fri 7/9/04	Thu 9/30/04
20	1.4.3		Calculation of needed design strength/coverage	60 days	Fri 7/9/04	Thu 9/30/04
21	1.5		Testing of Epoxies	60 days	Fri 7/9/04	Thu 9/30/04
22	1.5.1		Tension tests	60 days	Fri 7/9/04	Thu 9/30/04
23	1.5.2		Shear/peel tests	60 days	Fri 7/9/04	Thu 9/30/04
24			Choice of Baseline Extrusion Design and support Structure - Milestone	1 day	Mon 11/1/04	Mon 11/1/04
25	1.6		Design of 27ft. X 15ft.Mech. Prototype Using Commercial Extrusion	31 days	Fri 10/1/04	Fri 11/12/04
26	1.6.1		Design of bookend support structure	30 days	Fri 10/1/04	Thu 11/11/04

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ID	Task #		Task Name	Duration	Start	Finish
27	1.6.2		Design 4-layer extrusion structure	30 days	Fri 10/1/04	Thu 11/11/04
28	1.6.3		Decide upon handling/assembly method	30 days	Fri 10/1/04	Thu 11/11/04
29	1.6.4		Strong back design	30 days	Mon 10/4/04	Fri 11/12/04
30	1.6.5		Choose Epoxy to use	25 days	Fri 10/1/04	Thu 11/14/04
31	1.6.6		Design method for sealing ends of extrusions	30 days	Fri 10/1/04	Thu 11/11/04
32	1.7		Construction/Testing of 20ft. X 20ft. Mech Prototype Using Commercial Extrusion	105 days	Fri 11/12/04	Thu 4/7/05
33	1.7.1		Order/receive commercial extrusions	80 days	Fri 11/12/04	Thu 3/3/05
34	1.7.2		Assemble structure	15 days	Fri 3/4/05	Thu 3/24/05
35	1.7.3		Fill with water and measure deflections	5 days	Fri 3/25/05	Thu 3/31/05
36	1.7.4		Pressurize and measure deflections	5 days	Fri 4/1/05	Thu 4/7/05
37	1.8		Design and Build 8m x 8m Mechanical Prototype Using Custom NOVA Extrusions	180 days	Fri 4/8/05	Thu 12/15/05
38	1.8.1		Design Final Extrusion	30 days	Fri 4/8/05	Thu 5/19/05
39	1.8.2		Order Final Extrusion	45 days	Fri 5/20/05	Thu 7/21/05
40	1.8.3		Design of a 8m x 8m Mechanical Pototype	45 days	Fri 7/22/05	Thu 9/22/05
41	1.8.4		Construction/Testing of 8m x 8m Prototype	60 days	Fri 9/23/05	Thu 12/15/05
42			Complete Construction of 8m X 8m Mech. Prototype	1 day	Mon 7/11/05	Mon 7/11/05
43						
44	2.0		R&D of Assembly Process	185 days	Mon 8/9/04	Fri 4/22/05
49	3.0		R&D of Scintillator/Filling Process	153 days	Wed 9/1/04	Fri 4/1/05
55	4.0		Module Design	236 days	Fri 10/1/04	Fri 8/26/05
63	5.0		Full Scale prototype Design	133 days	Wed 6/1/05	Fri 12/2/05
69			Ready to Begin Construction of Full Size Prototype	1 day	Thu 9/1/05	Thu 9/1/05
70	6.0		Facility Design	300 days	Mon 1/3/05	Fri 2/24/06
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